AIR COMMAND HEADQUARTERS

OPERATIONAL RESEARCH DIVISION

STAFF NOTE 94/2

THE ESTIMATION OF CANADIAN AIRLIFT CAPABILITIES

by

Jay M.H. Adamsson

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ABSTRACT

A study was undertaken to analyze the capability of Air Command to complete the initial deployment required by Air Command Defence Plans. In the process of this study, a number of techniques were developed to provide an initial estimate of the capabilities of the Air Command transportation fleet. This staff note details the formulae used to calculate required time, minimum aircraft requirements, optimum aircraft mix, and cost of the airlift. Further tools that can be used in planning a more detailed airlift are also outlined.

RESUME

Une étude a été menée en vue d'analyser l'aptitude du Commandement aérien à compléter le déploiement initial exigé par les Plans de Défense du Commandement aérien. Au cours de cette étude, on a conçu un certain nombre de techniques permettant d'obtenir une première estimation des capacités de la flotte de transport du Commandement aérien. Cette note d'état-major décrit les formules utilisées pour calculer le temps requis, le nombre minimal d'aéronefs requis, le type d'aéronefs optimal et le coût du transport aérien. On énumère également d'autres moyens de planifier une opération de transport aérien plus complète.

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THE ESTIMATION OF CANADIAN FORCES AIRLIFT CAPABILITIES

1 - INTRODUCTION

1. The Operational Research Division of Air Command Headquarters was tasked to assist in the determination of Air Command capability to complete the initial deployment of personnel and equipment as called for in the Air Command Defense Plans [1]. The results of this study are documented in [2].

2. In order to complete this study, a number of formulae for estimating the resources and time required for an airlift were developed. This staff note documents the formulae developed in order to provide the required estimates.

3. The equations are given in a general form that can be applied to any airlift. The required data is listed in section 2, and is used throughout. Sections 3 and 4 give the formulae for calculating requirements. These formulae are to provide initial estimates of the airlift requirement. For actual planning purposes, more detailed tools are needed. Section 5 gives some of the existing tools to assist in detailed airlift planning.

2 - DATA REQUIREMENTS

Aircraft Data

4. In order to make use of the equations given in this staff note, data is required concerning two components of the airlift. The first set of data required concerns the aircraft being used. The second set involves the requirements of the airlift itself.

5. The following aircraft variables are used for the airlift calculations. Where necessary, a subscript will be used to distinguish between aircraft types throughout this staff note:

a. **R**: This variable gives the Emergency Flying Rate (EFR) of the aircraft. This is the rate in hours per day that the aircraft would be expected to operate during an airlift.

b. **P**: This is the average payload of the aircraft in either metric tonnes (MT) or pounds (lbs). This number is lower than the maximum payload for the aircraft because a maximum load is not taken on every trip during a deployment.

c. **C**: This is the operating cost for the aircraft in dollars per hour as given in [3].

d. **V**: This is the velocity of the aircraft in nautical miles per hour (nm/hr).

e. **n** : This is the number of aircraft used for the airlift.

6. This staff note deals with only Canadian Forces airlift capabilities. For this reason, only the two main Canadian transportation aircraft are considered. The two aircraft are the CC130 Hercules and the CC150 Airbus. The CC130 is at present the principal aircraft used for transport. The CC150 is expected to be available in the near future for cargo movement. The CC137 Boeing aircraft, which is currently being used for transportation, will soon be phased out of service. However, the given equations can easily be modified to account for this aircraft, if needed. The following table gives the current values for each of these variable for

the CC130 and CC150 aircraft. Not all cells of the table have been filled in due to security requirements.

Variable	CC130	CC150
R	-	-
P	11.4 MT 25,000 lbs	28.2 MT 62,000 lbs
C	$4394/hr	$5784/hr
V	275 nm/hr	460 nm/h

Table 1 - Variables for Canadian Transportation Aircraft

7. Where possible in the equations, the variables have been used in such a way that they do not refer to any specific aircraft. Where necessary, the subscript **1** will be used to refer to the CC130 aircraft, and the subscript **2** will refer to the CC150 aircraft. For example, $\mathbf{P_1}$ refers to the average cargo weight of the CC130 aircraft, and $\mathbf{P_2}$ refers to the average cargo weight of the CC150 aircraft.

Airlift Requirements

8. The ability to meet the airlift requirements using the Canadian fleet depends on a number of details concerning the airlift itself. The following information is required:

a. **d** : The one-way distance of deployment (in nm). Any deployment will probably originate from Canada, so this can be interpreted as the distance of the deployment location from Canada.

b. **W** : The total weight (in MT) of all equipment that has to be moved for the airlift.

c. **T** : The allowable time (in days) to complete the airlift.

3 - AIRLIFT CALCULATIONS FROM WEIGHT

How Long Will It Take?

9. The first question in most airlift problems is to determine how long the airlift will take, given a set number of aircraft resources to be used. The first step in this process is to determine the average distance an aircraft can fly in one day. In the case of only one type of aircraft being used, this is given by the formula:

$$nm\ /day\ /aircraft = VR \qquad (1)$$

For **n** aircraft, the total distance per day is given by:

$$total nm\ /day = nVR \qquad (2)$$

Each aircraft is capable of carrying a weight of **P** MT. Therefore, the total Tonne Miles per Day (TMPD) of the fleet is given by:

$$TMPD = nPVR \qquad (3)$$

This expression is a consistent method of expressing the maximum daily capability of a fleet of aircraft. The total requirement for the airlift, in Tonne Miles (TM) is given by

$$TM=2dW \qquad (4)$$

Then the total number of days required for the airlift is obtained by dividing **(4)** by **(3)** to obtain

$$t = \frac{2dW}{nPVR} \qquad \textbf{(5)}$$

The equation for a combination of aircraft is obtained in a similar manner to equation **(5)**, by calculating the TMPD for a combination of aircraft. The airlift time requirement for a mixture of CC130 and CC150 aircraft is given by:

$$t = \frac{2dW}{n_1P_1V_1R_1 + n_2P_2V_2R_2} \qquad \textbf{(6)}$$

What Is the Least Number of Aircraft That Can Be Used?

10. Another pertinent question concerns the least number of aircraft that can be used, and still allow for the completion of the airlift in time. Since the minimum aircraft requirement depends on the number of aircraft of each type in use, it is assumed that the number of CC150 aircraft is known. The formula will then determine the minimum possible number of CC130 aircraft that can be used.

11. The equation is formed by taking equation **(6)** and replacing the time **t** with the variable **T**, which is the longest allowable time for the airlift to take. It is then solved for the variable **n**.

$$n_1 = \frac{2dW - TP_2V_2R_2n_2}{TP_1V_1R_1} \qquad \textbf{(7)}$$

12. The only drawback of this equation, as was already mentioned, is that the number of CC150 aircraft has to be predetermined. However, since the fleet of CC150 cargo aircraft consists of only five aircraft, this should not be too difficult.

How Many Aircraft Should Be Used?

13. Equation **(7)** gives the minimum number of aircraft that can be used in an airlift. Adding more aircraft to the airlift will obviously shorten the time required to complete the airlift. The next question concerns the optimum number of aircraft. This is a difficult question due to the fact that there is no concrete definition of the optimum aircraft flow. Committing another aircraft will decrease the time, but does it decrease it enough to justify the committment of that aircraft? There are many possible solutions to this question, ranging from the commitment of all aircraft to complete the airlift in the shortest possible time, to using the minimum number of aircraft to avoid the commitment of too many resources to one single airlift.

14. One compromise between these two extremes is to keep adding more aircraft until the addition of one more aircraft will reduce the airlift time by less than one day. In mathematical terms, this is the point at which the derivative of equation **(6)**, given by

$$\frac{dT}{dn_1} = \frac{-2dWP_1V_1R_1}{(n_1P_1V_1R_1 + n_2P_2V_2R_2)^2} \qquad \textbf{(8)}$$

is equal to -1. Solving for this in terms of $\mathbf{n_1}$ gives the formula:

$$\textit{Optimum Number of CC130 Aircraft} = \frac{\sqrt{2dWP_1V_1R_1} - n_2P_2V_2R_2}{P_1V_1R_1} \qquad \textbf{(9)}$$

15. Once again, use of this formula requires a knowledge of the number of CC150 aircraft to be used, since the optimum number of CC130 aircraft varies with different numbers of CC150 aircraft. However, as for equation **(7)**, the small number of CC150 aircraft available makes it simple to calculate all possibilities.

How Much Does It Cost?

16. Also of interest to planning an airlift is the increased cost attributable to the airlift. This cost is expressed in terms of the cost per hour to fly each of the aircraft. It can be expressed in terms of the cost and the time required to complete the airlift:

$$Cost = (n_1 C_1 R_1 + n_2 C_2 R_2)t \qquad \textbf{(10)}$$

Expanding equation **(10)** by using equation **(6)** results in:

$$Cost = \frac{2dW(n_1 C_1 R_1 + n_2 C_2 R_2)}{n_1 P_1 V_1 R_1 + n_2 P_2 V_2 R_2} \qquad \textbf{(11)}$$

17. The formula in equation **(11)** can be simplified further if only one aircraft is being used in the airlift. The formula for only one type of aircraft is:

$$Cost = \frac{2dWC}{PV} \qquad \textbf{(12)}$$

As can be seen by this equation, if only one type of aircraft is being used, the cost of the airlift no longer depends on the number of aircraft being used. Adding more aircraft to the flow will neither increase nor decrease the cost of the airlift.

Sample Airlift

18. To demonstrate how these equations can be used to assist in the planning of a sample airlift, assume that an airlift is required with the specifications given in Table 2. Further assume that up to twenty CC130 aircraft are available, and two CC150 aircraft are available for cargo movement, and each is capable of flying 10 hrs/day.

Variable	Value
d	5000 nm
W	1500 MT
T	25 days

Table 2. Requirements for Sample Airlift

19. Using the available resources, the minimum amount of time that the airlift can be completed in is calculated using equation **(6)**. This equation gives a minimum time requirement for the airlift of 14.4 days.

20. A total of 25 days have been defined as the maximum time for completion of the airlift. Not all of the aircraft have to be used to insure that the airlift is completed on time. Using equation **(7)** gives a value of eleven CC130 aircraft. Hence, the option is present to use any amount of aircraft between 11 and 25 to complete the airlift.

21. The optimum number of aircraft to use can be calculated from equation **(9)**. This gives a value of 14 as the optimum number of aircraft. Using equation **(6)** gives a time requirement of 21.5 days to complete the airlift using 14 CC130 aircraft.

22. The cost of the airlift is calculated using equation **(11)**. With fourteen CC130 and two CC150 aircraft the cost of the airlift is $15.6 million.

4 - AIRLIFT CALCULATION FROM NUMBER OF CHALKS

How Long Will It Take?

23. Another method of specifying airlift requirements is to state the number of flights, or chalks, that are required. In this instance, only the number of flights that must be accomplished is important, and not the total weight of the airlift. An example of this situation would be for personnel movements. The CC150 aircraft has seating for a specified number of personnel. Therefore, the number of flights required to move all personnel would be known in this instance, and the total weight of the passengers is irrelevant.

24. For this section, a new variable has to be introduced. This variable, designated by **F**, describes the number of flights, or chalks, that are required. Again, $\mathbf{F_1}$ refers to the CC130 aircraft, and $\mathbf{F_2}$ refers to the CC150 aircraft.

25. If only one type of aircraft is considered, then the total distance that must be flown to complete the airlift is the round trip distance of the airlift multiplied by the number of times that the trip has to be made. In other words,

$$\textit{total distance} = 2dF \qquad \textbf{(13)}$$

The time required to complete this airlift is obtained by dividing equation **(13)** by the total distance the aircraft is capable of flying per day, given by equation **(2)**, to obtain

$$\textit{time to complete airlift} = \frac{2dF}{nVR} \qquad \textbf{(14)}$$

For a mixture of aircraft, the total time required is determined by solving equation **(14)** for each type, and taking the largest result.

What Is The Least Number of Aircraft That Can Be Used?

26. The least number of aircraft that can be used is determined by setting the time to complete the airlift in equation **(14)** equal to the maximum allowable time to complete the airlift, **T**. The equation is then solved for the number of aircraft, and the result is the smallest number of aircraft that can be used to complete the airlift on time.

27. For the CC130, the smallest number of aircraft is

$$n_1 = \frac{2dF_1}{TV_1R_1} \qquad \textbf{(15)}$$

For the CC150 aircraft, the smallest number is

$$n_2 = \frac{2dF_2}{TV_2R_2} \qquad \textbf{(16)}$$

How Many Aircraft Should Be Used?

28. The question of the optimum number of aircraft that can be used in this case is solved in a slightly different manner than in the previous instance. In equation **(9)**, the number of CC150 aircraft has to be specified before calculating the number of CC130 aircraft. This is because part of the load can be shifted from one aircraft type to the other type. In this instance, the exact number of trips for each aircraft is known. Therefore, the exact number of CC130 aircraft can be calculated using the criterion that the addition of one more aircraft will reduce the time of the

airlift by less than one day. This is solved by taking the time to complete the airlift, given by equation **(14)**, and setting its derivative to -1. Once this is solved, the resulting equation gives the optimum number of CC130 aircraft as:

$$\textit{Optimum number of CC130 Aircraft} = \sqrt{\frac{2dF_1}{V_1R_1}} \qquad \textbf{(17)}$$

29. Once this number is calculated, the number of CC150 aircraft needed to complete the airlift in the same amount of time is given by use of equation **(14)**. Since the value for $\mathbf{n_1}$ is known from equation **(17)**, the time to complete the airlift can be calculated, then used to calculate the value for $\mathbf{n_2}$ as:

$$\textit{Optimum number of CC150 aircraft} = \frac{F_2\sqrt{2dV_1R_1}}{V_2R_2\sqrt{F_1}} \qquad \textbf{(18)}$$

How Much Does It Cost?

30. The cost of the airlift is calculated in a similar manner to equation **(11)**. The time required for each aircraft type to complete their portion of the airlift is given in equation **(14)**. The cost attributable to each aircraft type is calculated and added together to obtain an overall cost figure of

$$\textit{Airlift Cost} = \frac{2dF_1C_1}{V_1} + \frac{2dF_2C_2}{V_2} \qquad \textbf{(19)}$$

Sample Airlift

31. Using the values in table 2, assume that the airlift requirement is for 100 chalks of the CC130 aircraft. Equation **(14)** gives the time required for the CC130 to complete the airlift as 14.5 days. The minimum number of CC130 aircraft required can be calculated from equation **(15)** as 15 aircraft. The optimum number of aircraft is given by equation **(17)** as 19 aircraft, which then gives a time to complete the airlift of 19 days, according to equation **(14)**. The cost of this airlift is calculated from equation **(19)** as $439 million.

5 - OTHER AIRLIFT PLANNING TOOLS

32. A number of other tools have been developed to assist in the planning of an airlift. The tools summarized in this section have been developed by the Operational Research Advisor at Air Transport Group Headquarters in Trenton, Ontario.

33. The program PLANNER [4] will plan an airlift given the weight to be moved and the route to be taken. It can be used to give an optimum number of aircraft, using a similar algorithm to that presented in equation **(9)**. It will also suggest the number of crews required to complete the airlift without significant delay, and position the aircrew in the optimum locations.

34. The next program, PLOADER [5], is designed to facilitate the placement of cargo into an aircraft for an airlift. It requires a list of cargo items to be moved, and the type of aircraft to be used. It will then give a list of items to be included in each chalk, accounting for aircraft size and weight limitations. The list will be optimized to complete the lift with the near minimum number of chalks possible.

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A study was undertaken to analyze the capability of Air Command to complete the initial deployment required by Air Command Defence Plans. In the process of this study, a number of techniques were developed to provide an initial estimate of the capabilities of the Air Command transportation fleet. This staff note details the formulae used to calculate required time, minimum aircraft requirements, optimum aircraft mix, and cost of the airlift. Further tools that can be used in planning a more detailed airlift are also outlined.

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